Quantum Scattering Interferometry in a Juggling Cesium Fountain Clock

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We have demonstrated a fundamentally new and highly precise scattering technique in our juggling cesium fountain clock.[1] We juggle two clouds of atoms by launching two laser-cooled clouds in rapid succession. The atoms in one cloud are prepared in a coherent superposition of the two clock states and the atoms in the other are prepared in one of the F, m_F ground states. When the two clouds collide, the clock states experience s-wave phase shifts as they scatter off of the atoms in the other cloud. Here we detect only the scattered part of the clock atom's wave function and, for this scattered wave, the relative phase of the clock coherence is shifted by the difference of the s-wave phase shifts for the clock states, $\delta_{30} - \delta_{40}$. The Ramsey fringes for the scattered atoms therefore have a phase shift of $\delta_{30} - \delta_{40}$. The s-wave phase shifts are generally of order $\pi/2$ - for the clock states scattering off of F=3 m_F states at 30 μK, we observe a 0.4 radian phase shift of the Ramsey fringes, which is a frequency shift of 0.25 Hz!

A key feature of this technique is that the phase shift of the Ramsey fringes is independent of the density of each cloud to lowest order. This allows the quantum scattering phase shifts to be measured with potentially μrad accuracy, in contrast to clock frequency shifts which are proportional to density and therefore difficult to measure to better than 10% accuracy. Physical pictures will be presented that contrast these measurements to usual cold-collision frequency shift of clocks.

Recently, we have observed these s-wave phase shifts as inelastic collision channels open and close. As we increase the magnetic bias field from 0 to 1 Gauss, it becomes energetically impossible for atoms to go to some Zeeman states in an inelastic spin exchange collisions. The closing of scattering exit channels leads to a series of steps of the s-wave phase shifts as a function of magnetic field. These, as well as the measurements at low magnetic field will accurately test and constrain our knowledge of cesium-cesium interactions. With such knowledge, future measurement using this technique may place stringent limits on the time variation of fundamental constants, such as the electron-proton mass ratio, by precisely probing scattering phase shifts near a Feshbach resonance.[2]

Supported by NASA, NSF, and ONR.

[1] R. A. Hart, X. Xu, R. Legere, & K. Gibble, Nature **446**, 892-895 (2007).
[2] C. Chin, & V. V. Flambaum, Phys. Rev. Lett. **96**, 230801 (2006).